HIGH CONTRAST FAST LIQUID CRYSTAL DISPLAY SYSTEM

5   Technical Field

The present invention relates generally to liquid crystal display (LCD) systems and, more particularly, to improvements in contrast of LC light valves operating in fast modes, including the ECB mode.

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Background Technology

A high performance, single panel LC projector preferably employs extremely fast-responding LC light valves for several reasons. For example, the high frame

15   necessary to suppress color sequential artifacts requires such fast response. Another reason is color fidelity; a slow responding light valve mixes colors, degrading color purity. However, the faster responding light valves do not provide the required degree of contrast. In fact, the mode

20   with the fastest response, known as the ECB mode, represents a worst case in that the polarization of the incident light is at 45° with respect to the LC boundary director (i.e., the optical axis direction of the LC boundary layer), resulting in maximum loss of contrast.

25   Consequently, slower operational modes are presently being used in such applications.

The present invention is directed to overcoming one or more of the problems or disadvantages associated

30   with the relevant technology.

Summary of the Invention

The invention is based upon the contrast of the ECB, and other modes wherein the polarization of incident light is not parallel or perpendicular to the LC director on the light-incident side, being limited by light reflected at the light incident surface of the light valve. A thin layer of birefringent LC material is formed at the interface of the LC material and the glass substrate when the cell is biased. This boundary layer causes a small reflection of the incident light. The reflected light does not have the same polarization direction as the incident light. Moreover, as a direct result of this reflection, the polarization direction of the transmitted light also changes. Both effects contribute to a loss of contrast.

Two embodiments of display systems wherein the detrimental reflections are reduced, eliminated or rendered harmless are disclosed. In the first embodiment, an intermediate layer of LC polymer with a particular director profile is interposed between the LC material and the glass substrate on the light incident side. Thus, when the cell is biased, the intermediate layer is between the glass substrate and the LC boundary layer. In the second embodiment, a hybrid aligned LC layer is provided between the glass substrate layers on the top (light incident side) and bottom. This LC layer is provided with a high pretilt, e.g., between about 45° and 90°, on the side adjoining the top substrate, and a low pretilt, e.g., less than 10°, on the side adjoining the bottom substrate. In either case, polarization of the reflections at the light incident side of the cell is not affected in such a way that contrast is reduced.

Brief Description of the Drawings

Figures 1a and 1b are diagrammatic illustrations of a prior art ECB cell in unbiased and biased conditions, respectively;

Figures 2a through 2d are diagrammatic illustrations of operational characteristics of the cell of Figures 1a and 1b;

Figure 3 is a diagrammatic illustration of an LC cell incorporating a first embodiment of the present invention;

Figures 4 and 5 are graphical representations of reflectance vs. wavelength in a practical example of ECB cells of the prior art and of the Figure 3 embodiments, respectively; and

Figure 6 is a diagrammatic illustration of an LC cell incorporating a second embodiment of the present invention.

Best Mode for Carrying Out the Invention

A cross section of a typical ECB cell 10, comprising upper and lower glass substrates 12 and 14, respectively, and LC bulk material 16 is shown in Figure 1a in its natural, unbiased or "bright" state, and in Figure 1b under high bias condition. The lines representing the LC material indicate the orientation of the LC molecules. It will be noted that, in the biased state, the LC material is divided into a central layer 18, wherein the molecules are oriented vertically, and upper and lower boundary layers 20 and 22, respectively, at the junctions of the LC material and the substrates.

In a ECB light valve application, as illustrated in Figure 2a, incident light I is polarized along axis S, at 45° to the optical axis of the LC cell 25. In the unbiased "bright" state, the cell acts as a quarter wave plate and causes a 90° rotation of the polarization (from S to P) of the reflected light which is passed to the screen by the polarizing cube 24. Conversely, in a high field, the bulk of the LC, layer 18, is oriented vertically and appears isotropic to the incoming light, i.e., it does not affect polarization. The thin boundary layers 20 and 22, on the other hand, are birefringent and must be compensated by a birefringent film (not shown). As the net birefringence of a well-compensated cell is close to zero, one would expect a very good dark state and, hence, a high contrast. However, it has been found that even with the best compensation efforts, prior art ECB cells exhibited a contrast substantially below that of TN cells. Critical analysis showed that the excess light leakage originates in the upper boundary layer. This intermediate anisotropic layer causes a different reflectivity for light polarized in the extra ordinary (Figure 2b) and the ordinary direction (Figure 2c). Two reflections, re and re', represented by dotted lines in Fig. 2b, occur at the boundary layer, reducing the amplitude of the transmitted wave Te at each passage. The result is reduced amplitude Te and, hence, a change in orientation of the exiting transmitted wave T, which now has a component Tp orthogonal to the polarization direction of the incident wave. Reflected waves re and re' (Figure 2b) also have strong components orthogonal to the input polarization and,

therefore, add to the light leakage in the dark state of the system, illustrated in Fig. 2a.

Two embodiments of LC cells, which operate with the desired fast response without concomitant reduction of contrast, are illustrated in Figures 3 and 6. In cell 26 of Figure 3, there is illustrated a modified ECB cell in a high field state. Interposing an intermediate, optically anisotropic layer 28 (LC polymer), with a particular director profile, between the upper glass substrate 30 and the LC material 28, shown under bias in bulk layer 32 between boundary layers 34 and 36, reduces reflections due to gradual transition of refractive index from glass 30 to boundary layer 34 to bulk 32. This anisotropic layer can either be a photo polymer or layers that have been evaporated obliquely, layers that have been etched or milled by an oblique particle beam, such as Argon ions. Further, the effective thickness of the combined layers, i.e. boundary layer and intermediate layer, can be tuned to one half of a wavelength, e.g. green, such that reflection vanishes at the wavelength. In a practical case, the LC indices are no=1.5, ne=1.7 and the boundary layer thickness is 70-100 nm, leading to a strong reflection of 1%-1.5% (Figure 4). By adding an intermediate layer with the same indices, for a total thickness of 160 nm, reflectivity is reduced, as show in Figure 5. Thus, intermediate layer 28 adjoins substrate 30 and LC boundary layer 34, while LC boundary layer 36 adjoins lower substrate 38. Thickness and anisotropy, i.e., ordinary (no) and extraordinary (ne) indexes, of intermediate layer 28 provide sufficient degrees of freedom that the combination of intermediate layer 28 and LC boundary layer 32 form a net isotropic

stack. An example of a suitable material for intermediate layer 28 is a LC (photo) polymer. The orientation profile of the LC director inside this intermediate layer can be manipulated in a number of well-known ways. For example, the orientation can be perpendicular to the substrate at the light incident side and gradually transition to parallel at the light exiting side.

A second means for reducing or eliminating surface reflections is modification of the alignment of LC molecules within cell 40, as shown in Figure 6. A very steep tilt angle (e.g., between about 45° and 90°) of LC layer 42 relative to top substrate 44 is established at the light incident side, while the angle is almost parallel (e.g., 0° to 10°) at the juncture of layer 42 and lower substrate 46. In the 90° case, the LC boundary layer adjoining upper substrate 44 is optically isotropic, whereas at decreasing angles the anisotropy increases. In the latter case, a desired compromise between speed and contrast can be achieved.

Functional Description

Critical analysis showed that the excess light leakage originates in upper boundary layer 20. This anisotropic layer causes a different reflectivity for light polarized in the extraordinary and ordinary directions, illustrated in Figures 2b and 2c, respectively. Two reflections, re and re', represented by dotted lines in Figure 2b, occur at the boundary layer, reducing the amplitude of the transmitted wave Te at each passage. The result is reduced amplitude Te and, hence, a change in

orientation of the exiting Transmitted wave T, which now
has a component Tp orthogonal to the polarization direction
of the incident wave. Reflected waves re and re', also
have strong components orthogonal to the input polarization

5   and, therefore, add to causing light leakage in the dark
state of the system.

Interposing intermediate layer 28, an LC polymer
with a particular director profile, between the LC material
and top substrate 30, as shown in Figure 3, reduces

10   reflections due to gradual transition of refractive index
from glass to boundary layer to bulk. Such a structure
represents the equivalent of an anisotropic graded index
layer which can serve as an antireflection layer for the
underlying (also anisotropic) LC boundary layer. Further,

15   the effective thickness of the combined layers, i.e.,
boundary layer 34 and intermediate layer 28, can be tuned
to one-half of a chosen wavelength, e.g. green, such that
reflection is totally eliminated at that wavelength.

A comparison of reflectance in the biased prior

20   art cell 10 (Figure 1b) and in cell 26 over a range of
wavelengths is graphically shown in Figures 4 and 5,
respectively. In the illustrated example, the LC indices
are: no = 1.5, ne = 1.7 and the boundary layer thickness is
70-100 nm. In uncompensated cell 10 reflectance is in the

25   range of 1% - 1.5% throughout the spectrum of interest
(Fig. 4). Reflectance in the case of cell 26, using a
parallel-aligned LC polymer, (Fig. 5) shows a great
improvement, i.e., is much diminished. Similar results may
be obtained with cell 36 of Figure 6, employing hybrid

30   aligned LC layer 42 with high pretilt on the light incident

side of top substrate 44 and low pretilt on the side
adjoining bottom substrate 46.

Other aspects and features of the present
invention can be obtained from a study of the drawings, the
5   disclosure, and the appended claims.